The Flexible Wing Project: Advanced Tailoring Strategies for Laminated Composite Materials

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Newton Research Collaboration Programme

4.5months	**Brazil**	**Two-way**

OBJECTIVES OF THE EXCHANGE

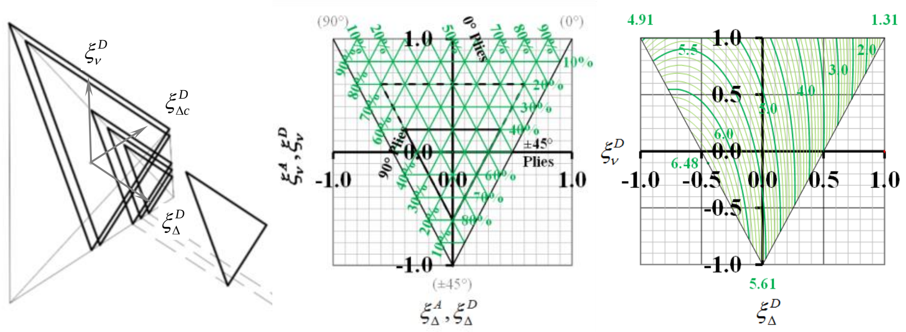
Manufacturers are beginning to consider the possibilities of moving away from traditional composite material designs but need further evidence that aero-elastically tailored composite materials can: produce weight savings; introduce aerodynamic efficiency and reduce manufacturing time without incurring cost penalties.

The research has developed advanced composite tailoring strategies using novel fibre reinforced architectures, with mechanical coupling properties. These properties can be either maintained or tailored through a novel ply termination scheme to change the laminate thickness. Most importantly however, all designs possess immunity to thermal warping distortions; hence they can be manufactured to the desired shape using a high temperature curing system. The research results have been exploited by a leading Brazilian airframe manufacturer for preliminary design of a new aero-elastically tailored wing.

RESEARCH UNDERTAKEN

A key aspect of the research involved the development of a special class of laminate, possessing Extension-Shearing Bending-Twisting coupling, necessary for optimised passive-adaptive flexible wing-box structures. The possibility of achieving a measurable drag reduction in cruise flight, without the cost or reliability issues associated with active control mechanisms, is of significant interest for achieving increased fuel burn efficiency, and meeting associated emissions targets. The introduction of passive Bending-Twisting coupling at the wing-box level has been previously demonstrated through laminate level tailoring with Extension-Shearing coupling only, but the limited design space and the possibility for ply terminations (to produce tapered thickness) effectively rule out this special class of laminate for practical construction. Results have revealed a vast laminate design space with Extension-Shearing coupling that can be maximised without the unfavourable strength characteristics associated with off-axis alignment.

The continuing requirement for more efficient manufacturing of composite structures has resulted in the recent development of Non-Crimp Fabrics (NCF) with the potential to reduce wet lay-up times by half, in comparison to traditional Unidirectional (UD) tape. Spread tow Non-Crimp Fabric (NCF) materials, e.g. C-Ply^{TM}, are now available in a range of areal weights and ply architectures, and correspond to the standard ply orientations employed in traditional UD material lay-ups. The benefit of NCF material may be offset by reduced design freedoms when a specific form of mechanical coupling behaviour is required, ply terminations must also be introduced and thermal warping distortion eliminated. Interrogation of the available lamination parameter design space was used to demonstrate the effect of applying ply termination constraints. Buckling factor contours have been mapped onto the lamination parameter design space to assess the bounds, under compression and shear loading, for infinitely long simply supported plates. Design heuristics, such as ply percentages have also been investigated.



The 3D Lamination parameter design space through which 2D cross-sections are taken to interrogate: ply percentages, indicating the sub-region used in practical design and; shear buckling contours (k_{xy}) for infinitely long plates with simply supported edges.

Original plans to manufacture specimens (for experimental validation) using the AFP facilities of the Lightweight Structures Laboratory at the Instituto de Pesquisas Tecnológicas (IPT), were found to be unnecessary as a result of the research; designs for NCF material were discovered for which there was no requirement for off-axis orientation, hence AFP facilities.

Plans to manufacture small scale specimens could not be undertaken within the revised time frame and schedule of the project. However, a significant quantity of spread-tow carbon fibre material (from collaborators Chomarat, France, and Oxeon, Sweden) was successfully imported into Brazil during the project, with the help of Alltec Materiais Compostos, who have agreed to help with manufacturing. A specialised mould, necessary for the Resin Transfer Moulding (RTM) of spread-tow material has been designed and manufactured in support of these ongoing activities.

Due to the reduced time frame of this project, initial plans to incorporate these new designs into a global Finite Element Analysis simulation have been revised; they will instead be applied to a wind-tunnel model design for a future collaborative project.

IMPACTS AND OUTCOMES

The research has had a direct and immediate impact on current design practice. It was incorporated into an advanced Continuing Professional Development (CPD) course on Unconventional Laminate Tailoring, delivered to a leading Brazilian airframe manufacturer during the preliminary design phase in the development of a new aero-elastically tailored wing.

A public lecture was given at the Research Centre for Gas Innovation (http://www.rcgi.poli.usp.br/events-2016/). The event was organised by journalist Karina Ramos.

Some of the research undertaken during the exchange has been published. All acknowledge support from the Newton Research Collaboration Programme:

1. York, C. B., and Almeida, S. F. M. (2016) Design Space Interrogation for New C-Ply Laminate Architectures. In: ECCM 17: 17th European Conference on Composite Materials, Munich, Germany, 26-30 June 2016
2. Mania, R. J., and York, C. B. (2016) Buckling strength of FML profiles of 'classic' versus thin-ply design, In: Research Issues of Applied Mechanics, Mania R. J. (ed.), Vol. 6. Statics, Dynamics and Stability of Structures, Lodz University of Technology Publishing House, Lodz, Poland, ISBN 978-83-7283-768-4.
3. Mania, R. J., and York, C. B. (2017) Buckling strength improvements for Fibre Metal Laminates using thin-ply tailoring. Composite Structures, 159, pp. 424-432.
4. York, C.B. (2017) On bending-twisting coupled laminates. Composite Structures, 160, pp. 887-900.
5. York, C. B., and Almeida, S. F. M. (2017) On extension-shearing bending-twisting coupled laminates. Composite Structures, 164, pp. 10-22.
6. York, C. B., and Almeida, S. F. M. (2017) Tapered laminate designs for new Non-Crimp Fabric architectures. Composites Part A. 100, pp. 150-160.
7. York, C. B. and Almeida, S. F. M. (2017) Effect of Design Heuristics on the Compression and Shear Buckling Performance of Infinitely Long Plates with Bending-Twisting Coupling. 21st International Conference on Composite Materials, Xi'an, China, 20-25 Aug 2017.
8. York, C. B., and Almeida, S. F. M. (2018) Effect of bending-twisting coupling on the compression and shear buckling strength of infinitely long plates. Composite Structures. 184, pp. 18-29.

The collaboration has helped to augment taught courses at the University of Glasgow; specifically, courses on Aircraft Structures and Materials (Finite element modelling and simulation) and Composite Airframe Structures, particularly in the context of current vs future design practice, which will help to enhance student experience. A Master's thesis project has also been completed at the University of Glasgow, using the new design data generated during the collaboration: examining the effect on material strength constraints of introducing mechanical coupling properties and taper.

A Memorandum of Understanding (MOU) is being pursued between IPT and the University of Glasgow for future projects that will require access to specialist composite manufacture and test facilities.

FUTURE PLANS

Further research collaborations are planned under FAPESP funding. Spread-tow material delivered to Brazil, from both Chomarat (France) and Oxeon (Sweden), will be used to fabricate test specimens in collaboration with Alltec Materiais Compostos and IPT; with whom an MOU for future exchange of staff and research students is being pursued. New hybrid material designs will be investigated with the objective of improving strength after impact; these will be tested is specialised facilities at the University of São Paulo.

Collaborative studies on aero-elastic tailoring have revealed important design parameters, e.g. wing aspect ratio, which are necessary to satisfy economic viability, associated with certification, etc. The manufacture of wing specimens are planned for wind tunnel testing with technical support from Embraer, involving non-conventional plies, optimization techniques and wing-box design for aero-elastic control.

ROYAL ACADEMY OF ENGINEERING

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